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Overview and Analysis of the links between "Models of Mobility" and "Models of Pollutant Emissions from Transport"

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Final report

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Table of content

Index of Tables

Foreword

As a reminder, objectives are the following :

- to complete the overview of models of mobility which already exist and of those under development, namely : SCENARIOS, STREAMS, STEMM, EUNET and POSSUM[1];
- to analyse the bridging methods between mobility models and emission models, especially the most relevant parameters which are involved in this following selected criteria : accuracy, amount and quality of data available, complexity of the method, etc. ;
- to overview the existing methods of linking, application advantages, and weaknesses and to draw recommendations to those who design and operate mobility models and those who design and operate emission models.

[1] It appears from the documents received that POSSUM does not directly belong to mobility models development.

I. Introduction

Environmental pressure from mobility growth is currently a major source of concern, but is difficult to forecast. Decision makers need to possess tools to assess the impact of transport on the environment and to subscribe to the overall aim of sustainable mobility.

Amongst environmental pressures, air pollution from traffic and non renewable fuel consumption are a main concern for present and future generations.

From research carried out, two main fields are investigated to assess the impact of mobility :

- knowledge of mobility determinants and their relationship with travel;
- knowledge of air pollutant generation and fuel consumption in connection with vehicle characteristics and usage.

These two fields are subject to extensive study but are performed in separate ways and links between mobility studies and air pollution generation from transportation are still lacking, especially regarding models already developed.

The first field attempts to build models from socio-economic determinants or from trip generation mechanisms which allow to evaluate, monitor and forecast problems such as : economic inefficiencies, congestion, etc. The second field develops models which assess pollutant emissions and fuel consumption from different types of vehicles and driving patterns.

Links exist between these models. Firstly, output data from mobility models prove to be essential input data for air pollutant emissions. Secondly, both types of models use common exogenous input data.

The main objective of this study is to analyse the links between mobility models and air pollutant emission models.

This final report includes :

- an overview on mobility models;
- a consideration on linking procedures with emission models, an opinion and possible reorientation of the research;
- a conclusion.

Mobility models will be described while focusing on aspects which concern linking with emission models and give more emphasis on STREAMS, STEMM and SCENARIOS.

Mobility models are numerous and complex. They can be classified in function of several criteria. This aspect needs to be clarified before starting the study.

II. Mobility Models

Two major categories of models can be distinguished :

- **econometric models,** which explain mobility as a function of the most significant economic variables;
- **network flow models,** which modelise traffic flow on a transport network in conjunction with socio-economic modules.

II.1 Econometric models

Firstly, general comments are expressed on econometric models and secondly, an analysis of the SCENARIOS project is carried out.

II.1.1 General considerations

Two different types of econometric models are investigated : the first studies gasoline consumption as a dependent variable, and the second studies volume of transport as a dependent variable.

Extensive analyses and studies have been performed since the first oil crisis to achieve econometric models explaining gasoline demand[2]. In these models, gasoline consumption can be considered as an approximation for demand for transport, and it represents a possible variable for inclusion in emission models. Gasoline consumption is explained by a measure of income and price. Gasoline demand models are carried out at a national level, which means that aggregated national supply and demand are examined. At a regional level, no studies have been traced.

The second type of econometric models are macro-scale models, where dependent variables are expressed in terms of volume of transport, e.g. number of kilometre-passenger, vehicle miles travelled, etc. These models use the same type of explanatory variables as those for gasoline demand models, at least as regards the most significant variables (i.e. measure of income and price). In general, both variable coefficients are expressed in terms of elasticity coefficients.

(i) Models of gasoline demand from transport are carried out by statistical treatment by means of time series relationships between economic variables. This makes it possible to estimate price and income elasticities relative to gasoline consumption. Models differ depending on various aspects :

- form of demand function;
- static or dynamic modelling;
- explanatory variables included;
- estimation techniques (i.e. statistical methods).

[2] see meta-analysis made by ESPEY, 1996

As a rule, functional forms of regression are chosen in order to get equation parameters equal to elasticities coefficient, e.g. a log linear functional form. All of these models consider income and price/cost as explanatory variables, introduced as exogenous inputs. Only a few other variables are taken into account in these models but they are weakly significant. Data (explanatory variables) are easily available and predictable[3], but only on a broad aggregated (national) scale. Dependent variable (variable of interest) is aggregated and can be expressed in consumption per capita, per household or per vehicle. Times series can be either yearly, monthly or quarterly.

Considerable attention must be paid to the estimation techniques, to make allowance inter alia for auto-correlation, heteroscedasticity and problems related to panel data estimation. By way of illustration, the mathematical concept of the Baltagi and Griffin (1983) model is given below in summary form.

Example 1 : BALTAGI and GRIFFIN (1983).

$$\mathrm{Gas} = \frac{\mathrm{Utilisation}}{\mathrm{Efficiency}} = \frac{\mathrm{distance}}{\mathrm{vehicle}} \cdot \mathrm{number\ of\ vehicles} \cdot \left(\frac{1}{E}\right) \quad \text{(i)}$$

$$\ln\left(\frac{\mathrm{Gas}}{\mathrm{vehicle}}\right) = \alpha_0 + \alpha_1 \ln\left(\frac{Y}{N_{pop}}\right) + \alpha_2 \ln\left(\frac{P_{GAS}}{P_{GDP}}\right) + \alpha_3 \ln\left(\frac{\mathrm{Nvehicle}}{N_{pop}}\right) + \alpha_4 \ln E + \varepsilon \quad \text{(ii)}$$

$$\ln(E) = \delta + \gamma(L)\left(\frac{Y}{N_{pop}}\right) + \beta(L)\ln\left(\frac{P_{GAS}}{P_{GDP}}\right) \quad \text{(iii)}$$

E	: Efficiency
P_{GAS}/P_{GDP}	: Real price of gasoline
Y/N_{pop}	: Real per capita income
$\mathrm{Nvehicel}/N_{pop}$	: Number of vehicle per capita
$\gamma(L)$ and $\beta(L)$	: Polynomial in the lag operator L: $Ly=y_{-1}$
ε	: Disturbance term.

As efficiency cannot be measured, it is assumed that it is a long-term function of the real price of gasoline P_{GAS}/P_{GDP} and (Y/N_{pop}). Gasoline consumption is normalised on a per vehicle basis (Gas/vehicle).

(ii) Models explaining mobility volume follow the same pattern as the earlier models. The dependent variable is now a measure of volume of transport. It can be expressed, on a national scale, in miles travelled per car (or light trucks or lorry) or in kilometre-passenger. The main explanatory variables are, once again, income and relative price of transport. Some models include other socio-economic variables, such as the number of licensed drivers, population of driving age, etc.

Models can also deal with modal choice, as in De BORGER et al. (1988), where the share of cars in total transport volume is explained by income and relative price of cars in relation to the overall price of transport.

[3] Variables can be forecast using various existing statistical techniques on the basis of the available observations.

Further investigations should be undertaken to take into account the effect of social heterogeneity, reflected mainly by the position of households in income distribution and generation effects (demographic characteristics), rather than just considering the temporal diffusion measured by income and price elasticities. BERRI (1997) recommends the use of longitudinal analysis which allows specification of a dynamic model using individual data (grouping data together in order to ensure homogeneity over time); this is called pseudo-panel estimation. This approach is also developed by SCENARIOS and is described in the next section.

Even if the variables involved in these types of models are significant, they do not cover the mobility determinants as a whole, and are highly aggregated. By way of an illustration, the mathematical concept of the GREENE (1992) model is representative of this aspect.

Example 2 : GREENE model (1992).

$VMT_t = a_0 + a_1 CPM_t + a_2 GNP_t + a_3 Drivers_t + a_4 VMT_{t-1} + a_5\ DUM57\text{-}65 + e_t$

VMT	: Vehicle miles travelled
CPM	: Fuel cost per mile
DRIVERS	: Number of licensed drivers
DUM57-65	: Dummy variable.
e	: Disturbance term

Remark : Model uses logarithms of all variables. It is presented by way of illustration, other alternative lagged adjustment models have been developed by Greene. The results from estimating this equation are provided in Greene (1992)

II.1.2 SCENARIOS

The first objective of SCENARIOS is "to explicit the impact of main influencing factors on the transport system : development of population, spatial patterns, transport system costs, mobility pattern, development of technologies, transport policy"[4].

Only Deliverable 1, concerning "External Factors"[5], is currently available. The aim is to describe External Factors, i.e. the socio-demographic and economic structure of European countries, and the data availability, describing these factors for a base year (1994) and to forecast and project (for the years 2020 and 2040) the development of population, economy and trade starting from this base year (1994). These external factors should then be introduced into other modules of the SCENARIOS project as the motorisation rate analysis.

II.1.2.1 External factors data.

Concerning data requirements, the study analyses data for EU member countries, including Norway together with Switzerland and neighbouring Eastern countries (Czech Republic, Hungary, and Poland). Various categories of External Factors are taken into account : Population, Labour Market, Economy, Technology, Trade and Transport. For each of these

4 CEC (Commission of the European Communities), 1996, *Transport RTD Programme, Summary of Projects resulting from the First Call for Proposals*, p. 25.

5 I.W.W. (Institut für Wirtschaftspolitik), 1997.

categories, a detailed set of indicators is proposed. For transport data which are the main points of interest, the following indicators are selected, at NUTS 0-3 level[6] :

- number of cars,
- number of motorcycles,
- number of trucks,
- number of coaches/buses,
- length of road networks (2-groups (motorways and other roads)),
- length of rail network (3 groups (2-track, electrified and other railways)),
- inland waterways,
- pipelines,
- transport volume (passengers and tons)
- transport volume (passenger kilometres and tons kilometres).

At the current stage of the research, SCENARIOS does not as yet intend to compile a database. It specifies only the data requirement and proposes an inventory for the different indicators. The report highlights inadequacies in the NUTS Zoning System. Indeed, NUTS is based on institutional partitions in each of the different countries and therefore each standard NUTS level will vary from one country to another depending on the size, population, economic and administrative power. SCENARIOS intends to extend the NUTS Zoning System in order to provide a structure within all regions of comparable size.

Considerable heterogeneity among countries concerning data availability is observed. SCENARIOS identifies three categories of countries according to their data availability :

- *High level* (first group) : Austria, Germany, Hungary, Denmark, Spain, United Kingdom;
- *Average level* (second group) : Czech Republic, Sweden, Finland, France, Poland, Ireland;
- *Low level* (third group) : Benelux, Greece, Italy, Switzerland.

II.1.2.2 Other developments of SCENARIOS : the motorisation rate

From contacts with the people in charge of this project, it would appear that econometric models will be built. They will differ from those discussed above as they will not deal with a measure of mobility but will try to explain the dynamics of motorisation using age cohort models. For this, emphasis will be placed on changes in the motorisation of the household and Economic Factors influencing demand for transport, based on expenditure surveys in Europe.

The principal econometric models developed by SCENARIOS belong to demographic ones (age cohort models). The main difference between the models presented above and those developed by SCENARIOS, is that these new models focus on the demographic approach

[6] NUTS (nomenclature of territorial units of statistics) is the official European regional unit. The collection of the European Union statistical data are based on this standard. NUTS 0 is the national level. The other level consists of smaller territorial units. 6 levels (0 to 5) exist. The smallest territorial units usually published is NUTS 3.

(longitudinal analysis) based on household expenditure survey and panel data estimation techniques.

This approach make it possible to assess, among others, car fleets, car ownership, car market changes. For this purpose, data are grouped together in cells or cohorts following the position in the income distribution of the household and the generation, in order to ensure behaviour homogeneity over time. This longitudinal analysis explains the use of the name of age cohort models. It introduces a dynamic dimension comparing individual behaviour at a precise point in time and explaining the changes in behaviour over time. MADRE et al. (1995) explain the use of the demographic approach as a critique of the traditional econometric models, where income is the main explaining variable (de facto, it cannot be the only one) and this approach reflects "the need to locate the analysis of motorisation in a precise temporal setting"[7]. These issues are also discussed by BERRI (1997) which highlights the dynamic heterogeneity of individual behaviour and the need for a longitudinal analysis within the framework of the modelling of transport demand and in the frame of forecasting motorisation behaviour and car fleet.

We present, by way of an illustration, a brief description of the mathematical concept used in the age cohort, on the basis of the works of GALLEZ (1997) on long-term car fleet projection[8].

Illustration of the Age cohort model[9].

The originality of the age cohort model lies in its expression of the motorisation rate as a function of demographic variables (generation) rather than income and prices, as in the earlier models. To this end, the age cohort model breaks down the observed rate $t_{a,p}$ (e.g. motorisation rate) into an age effect α_a, an effect from the date of observation β_p and a generation effect γ_k.

In the model, longitudinal analysis is used. It takes into account the generation effect, the position in the life cycle (age bracket) and the date of observation. A matrix T of dimension (n_a,n_p) is built, T comprises the rate per age *a* and per date of observation *p* of individuals (or household) into a specific population (e.g. household equipped with one car). Generation effects are found on the diagonal of T (elements $t_{a,p}$ i.e. interaction of the age and the date of observation).

The matrices diagonal is expressed by :

$$t_{a,p} = \mu + \alpha_a + \beta_p + \gamma_k. + \varepsilon_{a,p}$$

[7] MADRE et al., 1995, *Demographic Dynamic of Mobility in Urban Areas : A Case Study of Paris and Grenobe*, p.2.

[8] No deliverable is currently available about these last developments in SCENARIOS.

[9] Based on GALLEZ, 1997.

where t_{ap} is the rate per age and per observation date of individuals/household into a specific population,

μ a constant which corresponds to the average value of the observed rate,
a the age bracket,
p the period of observation,
k the cohort,
ε a disturbance term.
$a=1,...n_a$ $p=1,...n_p$ $k=1,.....n_k$

For each date of observation *p*, the projection t_p of the dependant variable is estimated by summing on the n_a age categories, the products of t_{ap} by the number of households (m_{ap}) of age bracket *a* and for observation date *p*. The car fleet projection on observed date p (P_p), can be obtained using :

$$P_p = \sum_{a=1}^{n_a} Va_{ap} \cdot Am_{ap} m_{ap}$$

where Va_{ap} is the average number of car per adult and Am_{ap} is the average number of adults per household for each (a,p) pair.

Introduction of income and prices into the age cohort model framework

The results, based on earlier models on motorisation rate estimation, shows that they are relatively independent of economic climate (see. Gallez 1997). Even if demographic aspects are predominant, the quantitative effects of economic factors on motorisation cannot be left out. Therefore, economic determinants of the growth of individual motorisation are introduced in the new formulation.

In this way, models such as ACECO, used by Gallez (1997), estimate the motorisation rate (π_{ap}) on the basis of the equation :

$$\pi_{ap}= \alpha_a + \gamma_k + a \log Y_p + b \log C_p + \varepsilon_{a,p}$$

where Y_p is an income indicator expressed as an annual index of total household consumption;
C_p is a price indicator expressed as an annual index of the average automobile expenses;
ε is a disturbance term;
α_a and γ_k are defined as previously.

The use of Age cohort/ longitudinal analysis is not restricted to motorisation rate (i.e. car fleet). The method can be extended to many other variables such as car ownership, structure of car fleets, etc.. Gallez (1997) also proposes that longitudinal analysis be used to study the car fleet replacement, putting forward the notion of the "survival" rate of the car fleet (instantaneous or longitudinal).

The possibilities of linking these models and SCENARIOS with emissions models regarding car fleet are discussed in Section III.4.

II.2 Network flow models

"Network flow models" are, unlike econometric models, based on more disaggregated data. These models modelise traffic demand taking into account a defined transport network structure and by means of the estimated "Origin-Destination" (O-D) matrix. The ultimate goal is to simulate traffic on a geographic network per time period.

The network is represented by links and nodes. Usually links are physical connections such as roads but it could also be logical links like operation and transfer between modes of transport.

Two types of nodes are used :

- Nodes representing a junction where three or more links meet or when a route changes its characteristics (e.g. from flat road to mountain road).
- The centroid nodes which represent origin zones and destination zones.

Each link of the network includes a start node, an end node and a link type. Different characteristics are coded on the link : distance, capacity, travel time/speed, up to delay for custom formalities, etc. Representations of links for road networks, rail, air, etc. are found depending on the level of detail covered by the model.

Matrices O/D represent the number of trips between each centroid node.

APAS 22[10] give an overview of the strategic or multi-national models available in the European Economic Area. Transport model structure is traditionally composed of four steps (see APAS 22 report). The APAS database includes 62 passenger models and 43 freight models, collected with several criteria (e.g. for passenger models) :

- scale (part of country, one country, part of Europe, European Union, Europe);
- area (in square km^2) ;
- scope ((part) of the home country, international);
- number of O/D matrices (for cars, public transport, air, sea, bicycle, pedestrian, others);
- number of trip purposes (0, 1, 2, ≥ 2);
- number of zones (0-200, 22-500, 55-1000, >1000);
- number of links in a road network (no network, 0-5000, 5000-10000, 10000-50000, >50000);
- time basis (year/month, day, morning peak, evening peak, day + peak, parts of the day average weekday);
- etc..

Areas covered can be local (e.g. urban level) and on a wide scale (see further on the modules developed in RTD Transport : STREAMS and STEMM project at a European scale). The zoning system is, in general, at NUTS 0,1,2 or 3 level.

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[10] CEC, 1996a, *Transport Research APAS Strategic Modelling*, VII - 22.

The final step of the traditional 4-step model assigns traffic on the networks. More details are given in the following section. Note that some models deal exclusively with the assignment taking O/D matrices as exogenous input.

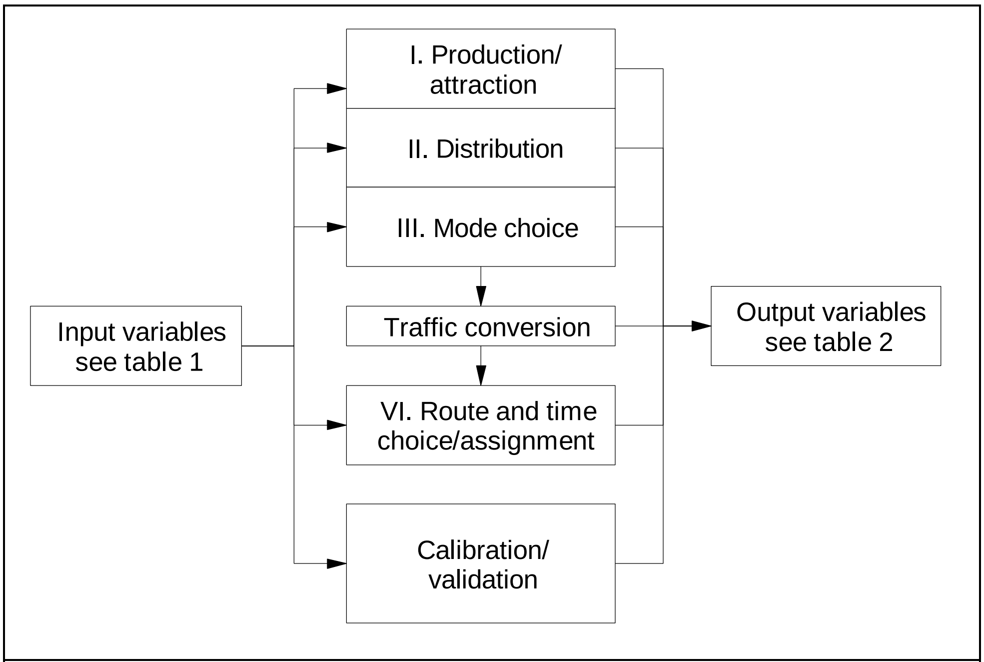
II.2.1 Four-step description.

Transport models are traditionally built on four main steps :

- trip generation/attraction model,
- trip distribution model,
- mode choice model and,
- assignment model.

A traffic conversion step (only a major issue for freight modelling), can be introduced between mode choice and assignment model. Finally, the main steps can be validated in a further calibration/validation step.

Figure 1 : The transport model



Source : CEC, 1996a, *APAS 22*, p.18

II.2.1.1 Generation/attraction models

This step estimates the number of trips (or amount of freight) leaving a zone, a centroid node, (generation trips) or entering a zone (attracted trips). The trip attraction aspect is usually less developed in models than trip generation. Two types of transport flows are distinguished :

i) Transport of passenger

The number of person/vehicle-trip originating in each zone (trip generation) are treated like a function of demographic and socio-economic variables : population, car ownership, income, etc. (see table 1). Estimation techniques are handled differently following trip purposes : business trips, journeys to work and social/leisure trips. This classification is not exhaustive and may be refined as needed. Methodology uses econometric tools to assess the number of trips per trip purpose. Input data are, amongst others, based on household surveys. In this frame, estimation is made on the basis of travel behaviour of groups, households or persons. The person-category approach, i.e. at the level of the individual, has several advantages as it has a better compatibility with other steps (modal choice, assignment) which are based more on individual behaviour of the travellers rather than on households.

Units of measure of the output (number of trips entering a zone) of the generation (or attraction) models is the number of vehicles or the number of passengers expressed per time period (see table 2).

Table 1 : Input data for transport models

Category	Passenger	Freight
Socio-economic data (generation, distribution, modal choice models)	• inhabitants per zone • working places • car ownership • income • growth factors • economic scenarios	• make and use tables or input output table per sector • value per ton • economic scenarios
Behavioural data (generation, distribution, modal choice and assignment models)	• distribution function • modal split function • assignment algorithm • occupancy rate	• distribution function • modal split function • assignment algorithm • loading rate • empty trips • logistic base form
Network data (Assignment models)	• distance • travel times • frequencies • traffic count • capacity • cost per mode • junction delays • turn penalties	• distance • transport times • frequencies • transfer cost • traffic/transport count • tonnes per vehicle • capacity • cost per mode

ii) For freight transportation

Mechanisms which govern freight demand are more difficult to assess because of the numerous different individual agents involved and the differences between sectors, logistic, transportation mode, etc. Estimation is made on the basis of input-output (I/O) tables segmented into sectors or products.

Units of measure of the output are measured in currencies or tonnes per time period.

II.2.1.2 Distribution models

This second step estimates where the "produced" trip will go to and where the "attracted" trip comes from. For this purpose, trips leaving or entering a zone are spread into an Origin/Destination (O/D) matrix of transport flows (and traffic loads) for the model zone. Matrices O/D represent the number of trips between each centroid node. Each element of the matrix O/D represents the number of vehicles/passengers (or number of tonnes moved), per modelling time period, with origin i and destination j, for all ij coded on the model zone (where i, j represent nodes).

II.2.1.3 Mode choice models

This third step aims at assessing the share of different modes of transport within mobility as a whole. Discrete choice models and random utility theory are used for this purpose. A subdivision of the original matrix from the distribution model is done into several O/D sub-matrices, one for each transport modes (car, rail, trucks, etc.). Modal choice can be a simple binary choice, for instance : car versus public transport (produces two sub-matrices) or multinomial choices with a series of hierarchical choices, car versus public transport and rail versus bus.

Table 2 : Output data for transport models

	Passenger	Freight
Production/ attraction	number of trips leaving a departing zone or entering a zone (centroid nodes)	amount of freight leaving a departing zone or entering a zone (centroid nodes)
Distribution	O/D matrix (i.e. number of trips between Origin i and Destination j)	O/D matrix; traffic loads
Mode choice	O/D matrix for each mode	O/D matrix for each mode
Assignment	link flows (number of trips between origin i and destination j choosing route k), link speed, junction delays, O/D travel cost	link flows, link speed, junction delays, O/D travel cost

II.2.1.4 Traffic units conversion

This intermediary step is a major issue for freight modelling. It converts the unity of measure into number of vehicles. Indeed, in freight modelling, the base unit used in the O/D matrices is tonnes. This transformation is needed as it is impossible to calculate transport cost on the basis of weight alone. This aspect is a minor issue for passenger modelling (car sharing).

II.2.1.5 Assignment

Trip assignment is the process by which route choice is modelled. For this purpose, trips, calculated in the previous steps, are assigned to a network. This results in a loaded network. The outputs are for each O/D pair : path flows, junction delays, O-D travel costs.

This task implies the taking into account of :

- the output of the previous steps,
- representation of road networks in form of one-way links (road section) and nodes (junctions), links characteristics : distance, capacity, speed-flow relationship,
- generalised cost functions (including, e.g. average journey time, journey length, fuel consumption, toll charge, number of stops).

One important aspect for emission assessment is that the model can infer average speed on the links (not the speed of the vehicle) in relation to the traffic flow (number of passenger cars per hour and number of lorries per hour). The speed-flow function depends on link characteristics : capacity, number of lanes, terrain characteristics (slopes, bends).

From the generalised cost function, a cost-flow function can be built. The assignment procedures can be either deterministic or stochastic[11]. Travellers choose paths which minimise their generalised cost functions (mainly time parameter). In the stochastic case, a random term is added to assignment algorithm.

II.2.1.6 Calibration/Validation

Once traffic loads are calculated, during the assignment step, a comparison is made with observed traffic loads. The improvement of the models can be made afterwards by modifying matrices O/D or the assignment algorithm in order to get a better match between observed and calculated data.

II.2.2 Comments

As shown in APAS studies, details of networks are, more or less, refined (capacity, speed, etc..), as well as details of O/D matrix (mode choice, route used), depending on targets aimed at. Higher the level of details, higher the complexity and the necessity to collect data.

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[11] We can further classify these models. They are :

- static, not taking into account variation over time. The traffic demand is assumed constant over the time period taken into account. Models are set up for a defined period of time. Average results over a time period are then obtained. For instance, matrix O-D expresses a total number of vehicles leaving point i to reaching point j during the period considered as a whole;
- dynamic for which, on the contrary, temporal dimension exists and driving patterns can be distinguished across a time period. The traffic demand varies across the modelled time period. The simplest method consists of splitting the time period modelled into a smaller time period. Problems like congestion and saturation could then be modelised.

II.3 STEMM

STEMM develops models for European passenger and freight transport, focusing on long-distance multi-modal transport. STEMM is the acronym for "Strategic European Multi-Modal Modelling". One of the major objectives of the STEMM project is "to identify and quantify factors affecting modal split and route choice for passengers and freight, particularly where intermodal chains are available and to develop a methodology for modelling intermodal chains for passenger and the freight transport"[12]. On the one hand, a passenger model has been developed by IWW Karlsruhe, BETA Strasbourg and Mkmetric Karlsruhe. We will outline below the main characteristics of this model. On the other hand, three freight models are implemented in STEMM. We choose to present the MDST model, which is a development of an existing model for cross-Channel freight movement which incorporate multimodal mode and route choices.

II.3.1 Passenger model

From information received, it would appear that Workpackage 1 develops an effective model for European passenger intermodal transport (the IWW European Passenger Model[13]). The model is designed and estimated on the basis of Trans-European inter-city traffic flows between NUTS2 or 3 regions (Belgium, the Netherlands, Luxembourg, Great Britain, Ireland, France, Spain, Portugal, Italy, Germany, Scandinavian and Alpine countries, Greece and Central and East European countries). STEMM deals with traffic between NUTS2 and NUTS2 or NUTS3 and NUTS3 level, and takes into account only about 5% of the total number of trips[14]. Moreover, at this level, up to 95% of urban and intraregional traffic is disregarded and therefore basic loads in zones of conurbation have to be estimated. The total road network covered by the model includes 14.000 undirect links and 10.000 nodes.

The European Passenger Model includes a classical sequence of steps :

- a two-step procedure to obtain O/D matrix, nesting together trip generation and distribution (estimated by a gravity model) which distinguishes three trip purposes : private, business and tourism,
- a mode choice (car, railway, air, coach and multimodal),
- a route choice / assignment model.

The network contains the following input link characteristics :

- road type,
- number of lanes,
- link length (in km),

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[12] CEC (Commission of the European Communities), 1996, *Transport RTD Programme, Summary of Projects resulting from the First Call for Proposals*, p. 29.

[13] Model developed by IWW Universität Karlsruhe, documents sent by Florian Heinitz.

[14] Information reported by F. Heinitz.

- name/number of the road,
- NUTS-II region,
- terrain type (slope, bend),
- tolls (in case of tolled links),
- flow data (where available).

For trip assignments, speed-flow and cost flow functions are coded for each link type. It is worth noting that in this framework, congestion could be highlighted and taken into account. Table 3 gives speed flow relationships chosen for passenger cars. Once the speed-flow and cost-flow relationship are known, the assignment procedure could be made.

Table 3 : Speed-flow relationships used in STEMM

Condition	vehicles per hour	speed-flow relationship (speeds in km/h)
"free-flow"	<1900	$v_p = \left(215.5 - 105 * \cosh\left(\frac{s+1}{10}\right)\right) * \exp\left(-10^{-3} * B\right) + 0.1 * \left(1 - \exp\left(3.272 * 10^{-3} * \left(Q_P + 2 * Q_G\right)\right)\right)$
"transition"	1900 .. 2375	$v_p = \coth\left(\left(\left(Q_P + 2 * Q_G\right) - 1880.84\right) * 10^{-3}\right) + 7.81$
"congestion"	>2375	$v_p = 10$
Q_P = passenger cars per hour, G_G = lorries per hour, bend parameter B = gon/km, s = number of lanes per direction Source : IWW European Passenger Model.		

The STEMM model is able to calculate average speeds on links using stable load patterns, and consequently, it could estimate the average speed on each O-D pair.

A very rough assumption is made on vehicle occupancy for each of the main trip purposes. But no distinction between categories of passengers cars is made.

Outputs of these models are aggregated to a high level, providing trip rates per NUTS3 zone and year and basic trip purpose (i.e. private, business, tourism).

II.3.2 Freight model

From information received concerning freight modelling, MDS-Transmodal[15] (workpakage 4) is still in its inception stage. Its main goal is to allow transport policy to be tested. The MDS-T model developer reported that he is concerned with the creation of a computer model which allows unitised freight flows to be analysed in specific European contexts, i.e. the Cross-Channel and Trans-Alpine corridors, at NUTS2 level.

[15] Documents sent by Mr. Sean Newton (MDS Transmodal).

The Trans-Alpine corridors is divided into a total of 54 zones : 11 zones in the South area of the Alps (mainly Italy) and 43 zones in Northern area (France, Germany, Switzerland, Austria, etc.). There is a link from each zone to its neighbours. However, they report that this simplified network is just taken into account to plot the routes. In fact, when selecting route/mode/vehicle choice, a commercial route planning system produced by Automobile Association is used.

It takes into account the following modes, for cross-Channel : Accompanied Trailer, Unaccompanied Trailer, Container (by sea or rail) and for Trans-Alpine : Trailers and Containers by road, Rail, route Roulante, Piggyback, etc.

Main inputs are O/D survey data, transport network databases and transport costs. Therefore this model is able to calculate distances, but it is no more than an assignment of traffic volumes (i.e. total volume by mode from a centroid to another).

Outputs give annual traffic volumes on all links. However, their program can be set up to model single day (or day and night), a week, a month, etc.. Their O/D matrices, measured in tonnes, are converted into number of vehicles. Given the network characteristics and the outputs, trip distances and average speeds can be calculated.

<u>Comments :</u>

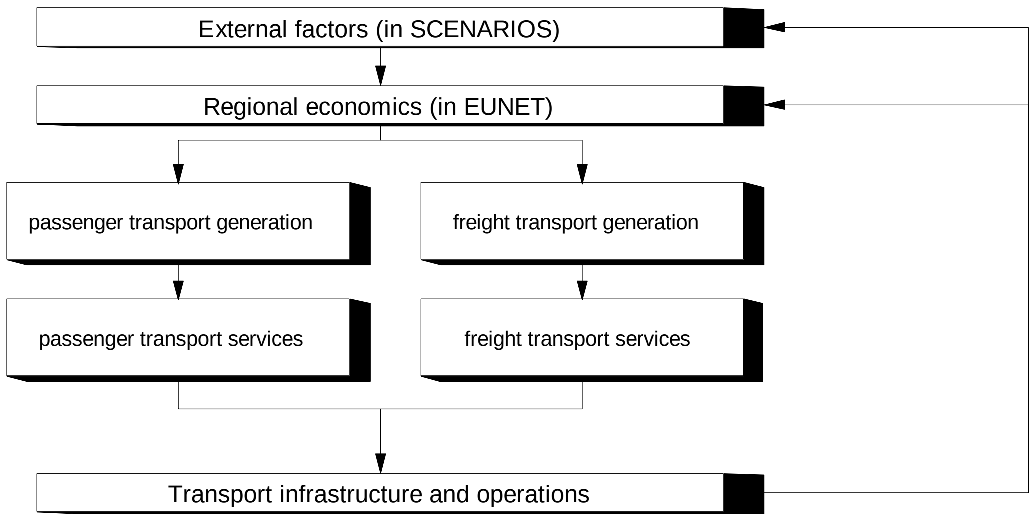
- Long distance model is still at a rough state;
- Traffic infrastructure is far from being entirely covered;
- No distinction between vehicles categories;
- Able to calculate average speed by links in function with their characteristics and the traffic flow.
- Number of starts (number of trips leaving a zone).

II.4 STREAMS

The objective is "to develop a methodology, and then to implement and test it in an operational model to present base scenarios on European transport developments. It will represent how external factors influence levels of mobility, and estimate the extent to which the European transport networks can cope with the resulting transport needs. (...) A model based on the methodology will be calibrated for all of Europe, and then used to provide forecasts of the patterns of mobility and of freight and passenger flows."[16] STREAMS is a very large model (shown in figure 1) which consists of three modules[17] or sub-models :

- a representation of external factors (developed in SCENARIOS);
- a regional economic module (developed in EUNET);
- a multimodal transport module which builds and validates a multimodal transport network.

Figure 1 : Overall model structure of STREAMS



Source : The STREAMS Models, deliverable D3, p2-2.

The model allows the calculation of total transport demand and transport infrastructure supply and estimates the passenger and freight load on each mode and route (developed in STREAMS). The first two parts (developed in SCENARIOS and EUNET) are implemented in STREAMS.

The network covered consists of 196 internal zones, at NUTS2 level or below, for the EU. It includes also 27 external zones for European countries outside the EU and 4 external zones for the rest of the world (see Annexe).

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[16] CEC (Commission of the European Communities), 1996, *Transport RTD Programme, Summary of Projects resulting from the First Call for Proposals*, p. 31.

[17] Marcial Echenique &Partners, 1996, *The Streams Model*, Deliverable D3, p.2-1.

The transport infrastructure will be represented by links and nodes needed for

- road network,
- rail network,
- inland waterway network,
- shipping and ferry network,
- air network,
- pipeline,
- access and intermodal transfers (ports, terminals, etc.).

As far as the multi-mode transport module is concerned, it is based on the classical 4-step modelling : generation, distribution, modal choice and assignment. This model allows the calculation of total transport demand and transport infrastructure supply, and estimates the passenger and freight load on each mode and route.

The level of details of transport infrastructure described in STREAMS[18] for road networks (similar for other modes) covers the following relevant items (for linking purposes with emission models) :

- link types, see table 4;
- link distance (in kilometres);
- travel time/speed (defined as average speed achieved by a typical car on the link in a situation without congestion from other traffic) taken to cross each road link. Conversion factors are included to take into account other road vehicles (which could be slower). Special attention is also given for urban link types and typical observed urban speed taking account the likelihood of delays at junctions and traffic lights, etc.;

Table 4. Road network link types

Class	Link type name	Notes
Interurban Roads	Toll motorways	Toll motorways*
	Non-toll motorways	Free motorways*
	Two-carriageways roads	Each carriageway has at least two lanes*
	One-carriageway roads	Each carriageway has only one lane*
Other Roads	Intrazonal road	To represent local capacity
	Urban Roads	If characteristics differ from interurban
	Road access from centroid	Access from the centroid to the road network
	Car border	Road link for cars only across the border
	Truck border	Road link for trucks only across the border
		*links categories are differentiated by country and by the number of lanes

Source : The Streams Models, Deliverable D3, p. 3-6.

[18] Marcial Echenique & Partners (1996).

- road capacity, measured as maximum one-directional flow per hour on the link measured in equivalent vehicles;
- exogenous traffic load (i.e. short local distance versus long distance traffic);
- others : charges are coded on the link, whether tolls have to be paid to use a link.

They use the following time-flow curves[19] for road link types :

$$\text{time} = \text{time}^0\left[1 + a\left(load/cap\right)^b\right] \qquad \text{if load < capacity}$$

$$\text{time} = \text{time}^0\left[1 + a + c\left(1 - \left(load/cap\right)^{-d}\right)\right] \qquad \text{if load > capacity}$$

where

time^0	is the free-flow time.
time	is the estimate of the time to actually traverse the link, based on the modelled congestion conditions. This is what is used in the path building in the model.
load	is the estimated total traffic volume on the link in equivalent vehicles. This is the outcome from the assignment procedure and subsequent modifications by any load averaging procedure which may have been applied.
cap	is the capacity of the link. Again it is measured in units of "equivalent vehicles" appropriate to this link type. The capacity represents the **maximum average throughput** that could be maintained consistently on the link during the time period.
a, b, c, d	are positive valued parameters that govern the shape of the time-flow curve, with values that are discussed below.

II.4.1 Passenger models

As in the previous models, trips are handled differently following trips purposes:

- business trip,
- journey to work,
- social and leisure trips.

The main modes taken into account are :

- slow modes (walk, cycle),
- car,
- bus/coach (local, scheduled and chartered),
- rail (local, inter city and high speed),
- air (scheduled and chartered).

Passenger transport demand is derived from the regional economic module (EUNET) which consists of a regional input-output (I/O) structure representing all industry sectors. Trips,

[19] Marcial Echenique & Partners, *The Streams Models*, Deliverable D3, pp. 6-16.

which are not directly connected with I/O tables, are handled apart. The output from trip generation processes are measured in the number of trips within a specified period of time.

II.4.2 Freight models

The main modes taken into account are :

- trucks,
- rail (bulk and container),
- ship (bulk and container),
- waterway,
- air,
- pipeline.

Demand of freight transport is derived from a regional input/output framework. Output is number of tonnes moved within a specified period of time.

From this first step of analysis : the STREAMS project, which includes other projects (EUNET, SCENARIOS) seems to be ambitious from a complexity point of view and requires an important amount of data. In contrast, the huge level of details involved allows immediate links with emission models.

<u>Comments :</u>

- High degree of description for the network.
- Able to calculate speed per links.
- Large model zone.
- Great variety of modes taken into account.
- Number of starts (number of trips leaving a zone).

III. Models of pollutant emissions from transport

III.1 Road emission models

III.1.1 General considerations on emission models

Road traffic emission models relate vehicle emission rates to driving conditions and other variables [CEC (1996)].

The main purpose of emission models consists of constructing transportation emission inventories at local, regional or national levels. These models also allow to predict the effects on emissions of changes in the design or operation of urban transportation systems and then to evaluate strategies to reduce air pollution.

In the context of an integrated modelling approach, emission models can be considered as tools allowing the calculation of air pollution emissions from a traffic network by using the data obtained from road assignment models (link flows, capacities and network geometry characteristics). Road assignment models and emission models represent two components of the modelling process. These components have been largely developed independently of one another.

In the framework of COST 319, work already carried out has revealed that there are plenty of models dealing with the calculation of exhaust emissions reported in international literature. According to the division of the activities within the COST 319 action on the inventorying tools, two main types of emission models have been distinguished :

- *bottom-up models (or microscale)*, tending to model emissions at street level, and from it allowing urban-scale inventories by an integration process, and
- *top-down models (or macroscale)*, following the opposite trends which consist of adopting the algorithm initially developed for country wide studies to microscales.

The COST 319 Working Group C1 focused on the bottom-up models and a large review of bottom-up inventorying models was conducted in co-operation with the DRIVE KITE Project. Such a review has covered 34 models applied for a number of European and non-European countries [Negrenti E. (1995)].

A comparison of microscale and macroscale traffic emission estimation tools was made [Zachariadis and Samaras (1995) ; Samaras *et al.* (1995)] in order to contribute to a "reconciliation" of macro- and microscale approaches, i.e. the attempt to match the aggregated microscale estimates with those of macroscale models, in order to check and possibly improve their reliability.

The purpose of this paper is not to propose a new review of emission models, which has already been done in other working groups of COST 319 but to propose a brief description of the relevant characteristics of emission models while focusing on the data requirement of these models in a linking perspective with traffic models.

III.1.2 General characteristics of emission models

As previously mentioned, the basic classification of emission models lays on **spatial and temporal scales** considerations. In this respect, two main types of models are distinguished : macroscale models and microscale models. Between these two extremes, several models exist that can be applied to one or the other scale with a certain degree of accuracy.

A more detailed characterisation of emission models implies the knowledge of different parameters. Among these, the main parameters concern the following items :

- **types of emissions considered** : hot emissions, cold-start emissions and evaporative emissions (only NMVOC emissions) with a further distinction for the latter between daily emissions, hot/warm soak emissions and running losses;
- **pollutants covered** : in general CO, CO_2, NO_x, HC and PM. Some models consider up to 254 different pollutants.
- **fleet description** : detailed vehicle categories, general vehicle categories, single vehicle, accounting for vehicle age and for future legislation, etc.;
- **traffic input :** vehicle mileage, flow rates, traffic counts, number of trips, etc.;
- **driving pattern** and **local traffic conditions** (e.g. driving at low acceleration rate, stop-and-go driving, slope of the street, altitude of the region) and the way by which they are taken into account : road class dependent emission factors, average speed dependent emission factors or emission factors expressed as a function of instantaneous vehicle speed and acceleration (or the product speed x acceleration);
- **output :** in general, emissions and fuel consumption in a more or less disaggregated form for the considered time period.

III.1.3 Input data requirement of emission models

In order to consider the possible linking between mobility models and emission models, it is important to firstly consider what are the input data required by emission models in order to carry out the calculation of emissions.

As the mobility models considered in the framework of this study (i.e. STEMM and STREAMS) address a rather low level of resolution (regional to national level), we considered two emission models able to work at this level : the COPERT II methodology [Ahlvik *et al.*, 1997] and the German-Swiss model [Hassel *et al.* (1993), Keller *et al.* (1995)].

The COPERT II methodology is the second update of the initial version prepared in 1989 for the CORINAIR 1985 emissions inventory [Eggleston *et al.*, 1989]. The updated methodology draws its main principles from the ongoing work in the framework of the COST 319 action and the MEET project. The COPERT II methodology can be applied at different levels of resolution. As a general rule, it is applied for the calculation of traffic emission estimates at a relatively high aggregation level both temporally and spatially (i.e. on a yearly basis at a national level). However, the methodology can also be used with a sufficient degree of certainty at a higher resolution too (i.e. urban emission inventories with a spatial resolution of 1x1 km^2 and a temporal resolution of 1 hour).

The German-Swiss model is the result of a five year joint German/Swiss research project undertaken in order to determine the emissions of all relevant categories of road vehicles in the two countries. The research has been conducted on behalf of the German Federal Environment Agency (UBA) in Berlin and the Swiss Federal Office of Environment, Forests and Landscape (FOEFL) in Berne. The work has been performed by several research institutes headed by the TÜV Rheinland. In order to make the results available to different user groups, a PC tool - the "workbook on emission factors" - has been developed. The results of the German/Swiss model in terms of emission factors can be used in a wide range of applications at both macroscale and microscale levels : e.g. for emission inventories at local, regional or national levels, for the evaluation of strategies to reduce air pollution, for environmental impact assessments, etc. A fine simulation of vehicle emissions is also possible as required, for instance, for the pollutant dispersion calculation from a vehicle flow considered as a line source or for the assessment of the emission behaviour of the vehicle flow passing a road cross-section. This is made possible by the use of emission functions which depend not only on the speed but also on a transient component (the product speed by acceleration).

Tables 5 and 6 summarise the input data required in order to calculate the emissions for a reference year with respect to the different emission types according to the COPERT II methodology and the German/Swiss approach. Data assumed to be obtained from a possible link with traffic models are presented in bold characters.

Table 5 *:* Input data requirement and availability of the data for the COPERT II methodology

Emission type	*Input data required*	*Availability of the data*
Hot emissions	• average speed-dependent emission factors in [g/km] for vehicle of category j	• available from the COPERT working group for various pollutants and vehicle categories
	• speed-dependent consumption factors in [g/km] for vehicle of category j	• available from the COPERT working group for various pollutants and vehicle categories
	• ***representative average speed or speed distribution for the three road types (urban, rural and highway)***	• national representative values available from COPERT 90 ; ***possible input from traffic models***
	• number of vehicles of category j $[h_j]$	• exogenous input data available from national car fleet statistics ; ***possible link with traffic models.***
	• ***average annual mileage per vehicle of category j*** $[v_j]$	• unavailable as independent statistical data in many countries and has to be estimated ; ***possible link with traffic models.***
	• ***share of annual mileage driven on road class k by vehicle category j*** $[d_{j,k}]$	• rarely available as independent statistical data in any European country and therefore has to be estimated ; ***possible link with traffic models.***
	• total annual consumption of fuel type l $[O_l]$	• statistical data available
Cold start emissions	• average trip length per vehicle trip $[l_{trip}]$	• unavailable in many countries for all vehicle classes, simplifications have to be introduced ; ***possible link with traffic models.***
	• average monthly temperature	• statistical data only available for outside parking.
	• total annual mileage driven by the vehicles of category j $[m_j]$	• can be deduced from h_j and v_j (cfr supra)
	• temperature and trip length dependent cold start correction factor	• available from the COPERT II working group
Evaporative emissions	• fuel volatility	
	• average monthly temperature and average monthly temperature variation	• statistical data only available for outside parking.
	• fuel volatility and temperature dependent emission factor	• available from the COPERT II working group
	• fraction of gasoline powered vehicles equipped with fuel injection [q]	• exogenous input data for national car fleet

Emission type	*Input data required*	*Availability of the data*
Evaporative emissions *(continued)*	• ***fraction of trips finished with hot engine [p]***	• unavailable in many countries for all vehicle classes, simplifications have to be introduced ; ***possible link with traffic models.***
	• ***fraction of trips finished with cold engine or with catalyst below its light-off temperature [w]***	• unavailable in many countries for all vehicle classes, simplifications have to be introduced ; ***possible link with traffic model.***
	• yearly average number of trips per vehicle per day	• calculated from l_{trip} and v ; ***possible link with traffic model.***
	• total annual mileage driven by the vehicles of category j [m_j]	• can be deduced from h_j and v_j (cfr supra)
Other parameters	• road gradient (only for heavy duty vehicle)	
	• emission correction factors function of vehicle mass, road gradient, pollutant specie, mean speed of the vehicle	• available from the COPERT II working group
	• vehicle load (only for heavy duty vehicle)	

Table 6 : Input data requirement and availability of the data for the German/Swiss methodology

Emission type	*Input data required*	*Availability of the data*
Hot emissions	• road network divided with respect to the different road section types and the different « traffic situations ».	• work has been done for Switzerland and Germany.
	• fleet composition	• exogenous input data available from national car fleet statistics ; ***possible link with traffic models.***
	• ***mileage driven by the different vehicle categories on the different road section types***	• ***expected from traffic model***
	• emission factors for each driving patterns which are characterised both by an average speed and a transient component (the speed-acceleration product)	• available from the joint German/Swiss project. Emission factors can be calculated for other user defined driving patterns if necessary.
Cold start emissions	• ambient temperature at the beginning of the trip	• the share of the starts occurring for each temperature class is deduced from daily temperature variation and daily start variation curves.

Emission type	*Input data required*	*Availability of the data*
	• travelled distance by the vehicle	• considered using trip length distribution as given by micro-census ; ***possible link with traffic models.***
	• parking duration before the trip	• parking duration distribution can be obtained from micro-census ; ***possible link with traffic models.***
	• driving behaviour at the beginning of the trip	• included by using suitable cycle.
	• ***number of starts per day and per vehicle***	• ***produced by a traffic model.***
	• cold start correction factor function of ambient temperature, travelled distance and parking duration before the beginning of the trip	• available from the joint German/Swiss project
Evaporative emissions **1) During parking (daily emissions)**	• vehicle fleet	• exogenous input data available from national car fleet statistical.
	• daily variation in ambient temperature	• monthly average values available.
	• evaporation factors during parking	• available from the joint German/Swiss project.
2) Hot soak emissions	• ***number of times the engine is turned off***	• ***considered as equal to the number of start operation which is expected from traffic model.***
	• frequency distribution of the travelled distance before the engine is turned off	• data obtained from micro-census ; ***possible link with traffic models.***
	• frequency distribution of the parking duration after the engine is turned off	• data obtained from micro-census ; ***possible link with traffic models.***
	• evaporation factors after stop as a function of parking duration and distance travelled before the engine is turned off.	• available from the joint German/Swiss project.
Other parameters	• road gradient	• characteristic of the road network available from surveys
	• vehicle load (only for heavy duty vehicle)	
	• altitude	

As shown in tables 5 and 6, there are two main types of data required by the models :

1) Data related to the emission and consumption factors at the right spatial and temporal scales.

The main data required by emission models consists of the emission and consumption factors expressed in [g/km], in [g/h] or in [g/kg fuel]. In general, these factors are provided by the model itself. The way the emission factors are defined determines their conditions of application. Two main categories of emission factors can be distinguished : those which are defined in a speed-dependent form as is the case in the COPERT II methodology and those for which the emission of pollutant is expressed as a function depending not only on the vehicle speed but also on a transient component (the acceleration or the product speed x acceleration). The emission factors used in the German/Swiss model belong to the latter category but have been related to different typical driving patterns occurring in typical traffic conditions on the different road section types. In principle, they apply to any vehicle kinematics and can therefore be used for calculations in the microscale which have to account for local traffic conditions (e.g. driving at low acceleration rate, stop-and-go driving, slope of the street, altitude of the region).

2) Data related to the traffic :

These data can be divided into three main classes :

- ***Mileage of each vehicle category*** :

  Both methodologies require the annual mileage per vehicle category and per road class or traffic situations as defined in the German/Swiss approach (for hot and cold emissions).

  The COPERT II methodology distinguishes three road classes (urban, rural and highway). In the German/Swiss model, a detailed division of the road network is considered by defining typical "traffic situations" for different basic road types (city streets, highways and motorways). Traffic situations are characterised by the features of a section road (for example "motorway general 120 limit", "main road outside built-up area: well developed, even bends" etc.). This is underlied in each case by a specific driving behaviour or a linear combination of various driving patterns which, for its part, is characterised by cinematic parameters (such as average speed, acceleration).

  For the application of the German/Swiss model to Switzerland [Keller *et al.*, 1995], the data related to the vehicle mileage were provided by a traffic model. The vehicle mileage is expressed in vehicle-kilometres per day or per year. The model allows a distinction between the different vehicle categories (passenger cars, light duty vehicle, heavy duty vehicle). However, the traffic structure into one particular vehicle category is not detailed by the traffic model. Nothing is stated about the share of the mileage that can be attributed to each sub-category or each technological concept (e.g. the share of the passenger cars equipped with a catalyst in the total mileage). In some cases, the vehicle usage can be very different with respect to the vehicle age, the cylinder capacity or the country of matriculation. In order to take into account these parameters and their evolution from year to year, a complementary tool has been developed using the notion of « traffic composition » (i.e. mix of vehicle sub-categories within a vehicle category).

- ***Number of start and stop operations :***

  Both cold and warm (i.e. after a short parking duration) engine starts have to be considered. In the German/Swiss model, an assumption is made that the total number of starts is equal to the total number of stop operations. These data can be obtained from the models.

- ***Vehicle fleet :***

  The number of vehicles per vehicle category and sub-category as well as the age distribution of the vehicle park per vehicle category are required as basic data for the calculation of hot emissions, cold start emissions and evaporative emissions. Additional fleet characteristics can also be required like for the German/Swiss model which considers the influence of the vehicle mileage on the exhaust gas emissions of catalysed vehicles so that, for that particular vehicle sub-category, the mileage has to be known.

Apart from these two main data classes, other parameters are also required such as : climatic conditions, fuel properties, road gradient, and load of the vehicle.

III.2 Non-road transport emissions

As mentioned further, models for the calculation of non-road transport emissions have not been specifically considered in a linking perspective in this study. Models for emissions from air traffic, railway traffic and ships are currently being studied within the framework of COST 319 action and the MEET project. The main features of these models are briefly presented in this section. For detailed information, we refer the reader to the studies mentioned below.

III.2.1 Air Traffic

Concerning emissions from air traffic, a review of existing inventories and methodologies was carried out as part of the MEET project [Kalivoda and Kudrna, 1997]. This report also presents a harmonised European methodology for estimating air pollutant emission from air traffic. The proposed methodology consider three main classes of air traffic : flights performed under Instrument Flight Rules (IFR), military operational air traffic and flights performed under Visual Flight Rules (VFR). An emission simulation program (*ATEMIS*) was used to create flight profiles and emission indices for thirty aircraft/engine combinations, representing the majority of IFR flights in Europe typical flight profiles were produced. These flight profiles can be divided into several sectors of constant performance and emission characteristics. Specific emissions for one aircraft/engine combination is expressed as function of : fuel consumption of the aircraft category per kilometre, pollutant emission index and distance flown. Because of the entirely different nature of military and VFR data available, the methodology used for military and VFR flights is different and based on hours of operation and average fuel consumption per hour.

III.2.2 Ships

Concerning emissions from ships, two methodologies were developed within the framework of the MEET project [Trozzi and Vaccaro, 1997] :

- a synthetic methodology for the estimate of consumption and emissions from known or easily available statistics on ship traffic without taking into account transient operations, port loading and unloading and auxiliary power generator. The basic application of this methodology is the emissions calculation in the case of ferry traffic where no information is available on harbour activities. Emissions are expressed as a function of : daily fuel consumption for each ship class, days in navigation of each ship class for the different engine types considered and appropriate average emission factors;

- a detailed methodology with the use of an organic fuel consumption data base on a ship-by-ship basis and the use of appropriate emission factors. This methodology is more appropriate in the case of a typical cargo, container or similar traffic in which the ship stays in harbour for some days. In addition to the synthetic methodology, different operating modes are distinguished : cruising, manoeuvring, hotelling, tanker offloading, auxiliary generators.

III.2.3 Railway traffic

Concerning the estimate of emissions from railway traffic, we refer to the study summarised in the Deliverable 17 of the MEET project [Jorgensen and Sorenson, 1997]. This report presents different methods for estimating railway emissions and it gives representative data for many of the different types of information which is required to perform calculations. The proposed calculation method is based on the estimation of the energy consumption (i.e. the energy required for the locomotive to move the train) for different trains and driving conditions. The energy consumption formula used is expressed as a function of average train speed and distance between stations. The emissions are then calculated using appropriate emission factors in g/kWh of power produced. Diesel engines and electrical power generation are distinguished.

III.3 Linking considerations with mobility models

Analysis, on the linking of emission models with mobility models, is mainly concentrated on network flow models, which seem more promising than the econometric models described in Chapter II.1. On the one hand, network flow models provide disaggregated data on volumes and transport flows by mode for each link and a detailed description of the network. On the other hand, econometric models deal with data which is to a large extend aggregated and provides no description of the network.

III.3.1 Econometric models

Econometric models estimate transport for a country or a region as a whole, on a yearly, quarterly or monthly basis. The only linking contribution that could be expected from econometric models is the possibility of considering forecast scenarios. Their ability to predict future changes of fuel consumption, vehicle mileage or vehicle fleet composition could be useful for the assessment of future air pollution reduction measures. The major disadvantage of existing models is the aggregate character of the data, which make it impossible to get measurements such as mean speed and to distinguish between the different categories of vehicles-travelling needed for emission model use. However, the latter parameters can be assessed from surveys and calculations (exogenous character).

New econometric models can be built to distinguish vehicles travelling (or other measures of travel demand) under different modes and to split, for example, urban from non urban vehicles travelling, provided statistics are available. Further investigation would be requested to assess this possibility. The existing econometric models, which have been constructed for other goals than emission assessment, partly satisfy the requirements of emission models, provided no simplifying assumption is made.

However, econometric models are able to predict fuel consumption, but without differentiating different fuel types. Once again, if data on total annual fuel consumption for each type of fuel could be found, models could be built on a time series basis, e.g. using as explanatory variables the relative price for each type of fuel. Econometric models can be linked with emission models, such as COPERT II, which calculates the total annual fuel consumption as a calibration parameter for estimating uncertain parameters (e.g. average annual mileage driven on each road class and for each vehicle category).

The evolution of the total annual mileage can also be exploited by emission models if some assumptions are made about the split between the different vehicle categories.

Furthermore, economic models do not provide any information on **car fleet** composition, which is of great interest for all types of emissions. In Chapter II, we have given an overview on age cohort model, used in **SCENARIOS**, which makes it possible to pertinently study car fleets. On the basis of documents received about SCENARIOS, age cohort models have already been used to forecast long-term projections of the car fleets at national, regional and local levels and one of the objectives of SCENARIOS is to harmonise methods in order to provide consistent forecasts for as many countries as possible. Principally, this project intends to use such models to forecast motorisation (number of vehicles per adult or household); forecast values depends on different assumptions regarding economic growth. Moreover, this project (see Deliverable 1 on External Factors and Data Availability) will provide a valuable source of transport data (passenger kilometres and tons kilometres, number of cars, motorcycles, etc.). It discusses data availability, and the NUTS level for each country. Future SCENARIOS interim reports will include discussions on Spatial Patterns and Modelling Feedback issues. Modelling a measure of mobility (kilometre passenger, vehicles miles travelled, etc.) would not be performed by SCENARIOS.

Further investigation, regarding SCENARIOS, has to be undertaken concerning the variables involved in the structure of the car fleet. Indeed, emission models require not only the total number of car per country/region but also the structure of the car fleet, i.e. : the share of diesel, gasoline and LPG cars, or the share of different vehicle cubic capacities and the age categories of each vehicle. Indeed, the different vehicle category splits, used in COPERT and German-Swiss models, are very detailed (e.g. 77 on-road categories have been defined in COPERT). SCENARIOS will not provide as much detail as required by emission models. But the method is claimed to project variables such as the rate of household equipped with diesel (gasoline or LPG) engines. In this field, economic data could also be used to estimate the share of the different motor types, on the basis of the sale of diesel engines and petrol-engines as an approximation for the share of each engine type in the car fleet.

III.3.2 Network flow models

III.3.2.1 Road transportation

For road networks, there is an asymmetry between individual and public transport. Individual transport is measured in the number of vehicles. On the contrary, public transport is usually measured in number of passengers. For linking purposes, only measurement in the number of vehicles can be used. In the case of models dealing with the number of passengers, the model must be able to convert this value into the number of vehicles.

From our analysis, in general, mobility models cannot directly provide emission models with usable data. Adjustments and approximations are necessary. According to emission types, three cases are distinguished.

<u>Hot emissions</u>

Considering data requirements previously presented (cf. table 5 and 6), the main incomplete data for hot emission calculation are the following :

- number of vehicles per category,
- kilometres driven per vehicle category on different road section types,
- average speed per road type taken into account (COPPERT) or allocation of typical traffic situations to the road network with respect to different road section types (GERMAN/SWISS model).

However mobility models provide :

- number of vehicles per mode on each O/D trip and the paths/route chosen for each trip,
- average speed of a representative vehicle in function of road link characteristics (bends, slopes) and in function of the flow on the link.

From mobility models, it is thus possible to infer for each O/D trip : the number of vehicles travelling per mode and the average speed from the origin to the destination (knowing the average speed on each link type travelled). Trip distance, number of kilometres travelled per time period, number of starts can also be deduced from the input and output of the mobility models.

Matching problems between hot emission calculation and mobility models remain in the calculation of kilometres driven per vehicle category and of kilometres driven per road type.

Firstly, mobility models can only distinguish the share of kilometres driven by car, bus/coach and by truck. In order to reconcile them with emission models, two solutions are envisaged :

- to refine mode choice models by splitting existing modes into sub-categories, for instance, by splitting the O/D matrices for cars into sub-matrices differentiating car sub-categories (fuel types and technological concepts). It should be evaluated to see the possible level of dis-aggregation that can be achieved and at which cost,
- to use statistical data on the car fleet and to weight the number of vehicles on each O/D pair per the share of the different vehicle categories including year per year considerations. This alternative can easily be operational but needs to assess the accuracy of the method.

Secondly, differences are observed in the road typologies used for mobility and emission models. A homogenisation and a standardisation will make the link easier between both models. For instance,

- COPERT II emission model differentiate only three road types (urban, rural and highways),
- German/Swiss emission model differentiates for three basic road types more than 170 so-called "traffic situations" for the different vehicle categories,
- mobility models like STREAMS differentiate 9 road type links (cf. table 4). These data were not provided for STEMM.

Attention must be paid to the fact that mobility models are a modelisation of the reality and the output data still remains an estimation associated with uncertainty. It is perhaps negligible for the objectives for which mobility models have been initially built (analysis of congestion, economic inefficiencies, alternative development patterns, etc..) but for linking with emission models, we have to assess the degree of certitude needed for input data (average speed, trip distances, etc.) to get acceptable results. Finally, the transportation network area studied with mobility models is still partly covering the actual transport network. Therefore no validation with fuel consumption statistics is possible at a national level.

Cold start emissions

Considering cold start emissions, apart from meteorological parameters and fuel properties, the data required that could possibly be supplied by mobility models concern :

i. referring to COPERT :
    - average trip length per vehicle trip ;
    - total annual kilometres of the vehicle for each category.

ii. referring to the German/Swiss model :
    - distance travelled by the vehicle;
    - number of starts per day and per vehicle;
    - parking duration before the trip.

The travelled distance and the number of starts per day and per vehicle can be supplied by mobility models with the same remarks as for hot emissions while considering the vehicle category split. However, the number of starting operations is unknown. To find it, we can make the restrictive assumption that each trip leaving a zone is considered as a start.

Concerning parking duration distribution before the trip, further information has been requested from mobility model developers in order to establish if this parameter can be provided one way or another.

New developments in cold start emission modelling [Sérié et Joumard, 1997] consider the driving pattern at the beginning of the trip using the average speed as additional data. This last parameter is available from the mobility models.

Cold start emissions also depend on the outside temperature which can be different following the parking location of the vehicles (indoor, outdoor). This aspect is not considered in the models and requires additional data concerning the share of vehicles parked in an indoor heated parking. Up to now, neither mobility models nor emission models consider this aspect.

Evaporative emission

As far as evaporative emissions are concerned, similar uncertainty with cold start emissions remains with regard to the parking duration between trips. The same remark as for cold start emission has to be made concerning parking location.

In order to solve the problem, COPERT II suggests a methodology for evaporative emission calculation. It requires many parameters that are, most of the time unavailable and have to be estimated. These parameters are the following :

i. fraction of trips finished with hot engines,

ii. fraction of trips finished with cold engines or with catalyst below its light-off temperature,

iii. yearly average number of trips per vehicle per day,

iv. total annual mileage of each vehicle category.

Referring to the German/Swiss model and for the same purpose, other parameters have to be estimated :

i. number of times the engine is turned off,

ii. frequency distribution of the travelled distance before the engine is turned off,

iii. frequency distribution of the parking duration after the engine is turned off.

In principle, the fraction of trips finished with hot engines and the fraction of trips finished with cold engines or with catalysts below its light-off temperature, can be determined knowing the trip length distribution and the ambient temperature. The number of trips per vehicle and per day and the total annual mileage of the vehicle category can also be determined processing the output data of mobility models. The same remark like for hot emissions concerning the vehicle category split is valid. The number of times the engine is turned off can be estimated making the assumption that it is equal to the number of trips arriving at a zone. These considerations need to be investigated further.

III.3.2.2 Non road transport

In a linking perspective, the road network must be distinguished from rail, ferry and air networks. In opposite to the road network, it should be said that, for air and rail networks, statistical data are easily available and observable so that linking with mobility models is a minor problem as compared to the road networks. Indeed, in latter case, observable disaggregated data are not easily available and the implementation of mobility models into emission models is hence justified. However, network flow models provide useful information concerning the infrastructure of transport, as previously mentioned, for STREAMS. For rail, ferry and air networks, different type of links are detailed, on each link the distance, a measure of travel speed and the capacity are coded. Moreover assignment models provide the flux on each link. Operation of transfer (like air operation) are also modelled with a different detail level. However, exogenous variables, mentioned in Section III.2, are important for linking (e.g. the category split of ferries, aircraft) and must be taken into account.

IV. Conclusion

This report shows that the links between emission models and mobility models are ultimately some-what limited. The fundamental reason for this is that existing emission models use emission functions which include a relatively restricted number of variables of which only a few can be provided by mobility models. Moreover, the design of mobility models can either be rather simple (econometric models) or very complex (network flow model). Considerable work has been undertaken on these last models, especially for road transport which is the most worrying for the environment. This is the reason why this study focuses especially on **road transport**.

As **econometric models** are conceived rather simply, linking is limited to the following inputs : fuel consumption, average kilometre-passenger travelled expressed per time period on a national scale in function of income and price/cost variables. These models do not provide any information on car fleets. In this field, SCENARIOS takes an original approach because it focuses on car fleets as a whole (motorisation rate) and that in function of demographic variables as well as conventional economic variables. Major purpose of these model is the possibility of forecasting and projecting variables of interest at a national level, for future years. Whilst these models analyse mobility as a whole, they allow easy calibration with fuel consumption statistics.

In contrast, the **network flow models** require a vast amount of information, because they take wide socio-economic aspects into consideration as well as transport network characteristics. Concerning socio-economic aspects, two inputs for COPERT II, the German/Swiss model and MEET, can be assessed : the number of trips per day and per purpose and the vehicle fleet considered as a whole or disaggregated in a few categories. In fact, models like STEMM and STREAMS consider transport modes rather than the disaggregated vehicle categories considered in emission models. For passenger transport on the road network, STEMM and STREAMS consider the following modes : car and bus/coach. For freight modelling, STREAMS deals with trucks and STEMM distinguishes trailers, containers , piggybacks, etc. Consequently, mobility models are not able to distinguish kilometre-travelled for the various vehicle categories taken into account in emission models : fuel type (Gasoline, Diesel, LPG) and other technological concepts (e.g. catalyst).

But the central element of network flow models stems from the transport network characteristics. More specifically, it is the links (and nodes) on which the main inputs for emission models (like COPERT II, German/Swiss model and MEET) are coded or calculated (distances travelled, speed-flow function, number of vehicles travelling, etc.).

This raises important issues. Firstly, the quality and quantity of information to be coded on the link[20], and secondly, the adequacy of the O/D matrices for the transport network reality (zone

[20] *Link characteristics considered in STEMM :* road type, number of lanes, link length (in km), name/number of the road, NUTS-II region, terrain type (slope, bend), tolls (in case of tolled links), flow data.

Link characteristics considered in STREAMS : link types, link distance (in kilometres), travel time/speed taken to cross each road link, road capacity, exogenous traffic load, others (e.g. tolls).

covered, level of detail, etc.). Finally, in order to calculate cold start and evaporative emissions, we need to calculate trip length distribution for each vehicle category. From the information available, it would appear that mobility models assess average trip length per mode of transport. A minor problem is the inadequacy of the different typologies used by both types of models (e.g. for road link types). It could easily be solved by matching emission and mobility models.

For non-road transport, studied in STEMM and STREAMS, the same considerations as for road transport apply.

Consequently, it can be seen that the design and use of the flow models are time and information consuming. Depending on the means provided, it is clear that their level of complexity is not necessarily synonymous with accuracy.

Finally, mobility models are designed by people with different aims from those pursued by those working on emission models and this is why these models are not built on a compatible form. One way to overcome this problem would be to develop an integrated modelling approach.

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VI. ANNEXE : The STREAMS zoning system

Country	No	Zone Name	NUTS 1995 or equivalent Code	Internal External	Centroid
Österreich	1	Burgenland	AT11	Internal	Eisenstadt
	2	Niederösterreich	AT12	Internal	St.Pölten
	3	Wien	AT13	Internal	Wien
	4	Kärnten	AT21	Internal	Klagenfurt
	5	Steiermark	AT22	Internal	Graz
	6	Oberösterreich	AT31	Internal	Linz
	7	Salzburg	AT32	Internal	Salzburg
	8	Tirol	AT33	Internal	Innsbruck
	9	Vorarlberg	AT34	Internal	Dornbirn
Belgique / België	10	Bruxelles / Brussel	BE1	Internal	Bruxelles / Brussel
	11	Antwerpen	BE21	Internal	Antwerpen
	12	Limburg (BE)	BE22	Internal	Hasselt
	13	Oost-Vlaanderen	BE23	Internal	Gent
	14	Vlaams Brabant	BE24	Internal	Leuven
	15	West-Vlaanderen	BE25	Internal	Brugge
	16	Brabant Wallon	BE31	Internal	Wavre
	17	Hainaut	BE32	Internal	Charleroi
	18	Liege	BE33	Internal	Liege
	19	Luxembourg (BE)	BE34	Internal	Arlon
	20	Namur	BE35	Internal	Namur
Deutschland	21	Stuttgart	DE11	Internal	Stuttgart
	22	Karlsruhe	DE12	Internal	Mannheim
	23	Freiburg	DE13	Internal	Freiburg im Breisgau
	24	Tübingen	DE14	Internal	Tübingen
	25	Oberbayern	DE21	Internal	München
	26	Niederbayern	DE22	Internal	Landshut
	27	Oberpfalz	DE23	Internal	Regensburg
	28	Oberfranken	DE24	Internal	Bamberg
	29	Mittelfranken	DE25	Internal	Nürnberg
	30	Unterfranken	DE26	Internal	Würzburg
	31	Schwaben	DE27	Internal	Augsburg
	32	Berlin	DE3	Internal	Berlin
	33	Brandenburg	DE4	Internal	Potsdam
	34	Bremen	DE5	Internal	Bremen
	35	Hamburg	DE6	Internal	Hamburg
	36	Darmstadt	DE71	Internal	Frankfurt am Main
	37	Giessen	DE72	Internal	Giessen
	38	Kassel	DE73	Internal	Kassel
	39	Mecklenburg-Vorpommern	DE8	Internal	Rostock
	40	Braunschweig	DE91	Internal	Braunschweig
	41	Hannover	DE92	Internal	Hannover
	42	Lüneburg	DE93	Internal	Lüneburg
	43	Weser-Ems	DE94	Internal	Oldenburg
	44	Düsseldorf	DEA1	Internal	Düsseldorf
	45	Köln	DEA2	Internal	Köln
	46	Münster	DEA3	Internal	Münster
	47	Detmold	DEA4	Internal	Bielefeld
	48	Arnsberg	DEA5	Internal	Dortmund
	49	Koblenz	DEB1	Internal	Koblenz
	50	Trier	DEB2	Internal	Trier
	51	Rheinhessen-Pfalz	DEB3	Internal	Mainz
	52	Saarland	DEC	Internal	Saarbrücken
	53	Sachsen	DED	Internal	Leipzig
	54	Dessau	DEE1	Internal	Dessau
	55	Halle	DEE2	Internal	Halle
	56	Magdeburg	DEE3	Internal	Magdeburg
	57	Schleswig-Holstein	DEF	Internal	Kiel
	58	Thüringen	DEG	Internal	Erfurt

Source : STREAMS, Annexe 1, pp. A1, A-5.

The STREAMS zoning system (continued)

Country	No	Zone Name	NUTS 1995 or equivalent Code	Internal External	Centroid
Danmark	59	Vest for Storebælt	DK11 (DK001-7)	Internal	København
	60	Hovedstadtsregionen and Øst for Storebælt	DK12 (DK008-F)	Internal	Arhus
España	61	Galicia	ES11	Internal	Santiago
	62	Principado de Asturias	ES12	Internal	Oviedo
	63	Cantabria	ES13	Internal	Santander
	64	Pais Vasco	ES21	Internal	Bilbao
	65	Comunidad Foral de Navarra	ES22	Internal	Pamplona
	66	La Rioja	ES23	Internal	Logrono
	67	Aragón	ES24	Internal	Zaragoza
	68	Comunidad de Madrid	ES3	Internal	Madrid
	69	Castilla y Leon	ES41	Internal	Valladolid
	70	Castilla-la Mancha	ES42	Internal	Toledo
	71	Extremadura	ES43	Internal	Mérida
	72	Cataluña	ES51	Internal	Barcelona
	73	Comunidad Valenciana	ES52	Internal	Valencia
	74	Islas Baleares	ES53	Internal	Palma de Mallorca
	75	Andalucia	ES61	Internal	Sevilla
	76	Región de Murcia	ES62	Internal	Murcia
Suomi / Finland	77	Uusimaa	FI11	Internal	Helsinki
	78	Etelä-Suomi	FI12	Internal	Tampere
	79	Itä-Suomi	FI13	Internal	Kuopio
	80	Väli-Suomi	FI14	Internal	Jyväskylä
	81	Pohjois-Suomi	FI15	Internal	Oulu
	82	Ahvenanmaa / Åland	FI2	Internal	Maarianhamina
France	83	Île de France	FR1	Internal	Paris
	84	Champagne-Ardenne	FR21	Internal	Reims
	85	Picardie	FR22	Internal	Amiens
	86	Haute-Normandie	FR23	Internal	Le Havre
	87	Centre	FR24	Internal	Orleans
	88	Basse-Normandie	FR25	Internal	Caen
	89	Bourgogne	FR26	Internal	Dijon
	90	Nord-Pas-de-Calais	FR3	Internal	Lille
	91	Lorraine	FR41	Internal	Metz
	92	Alsace	FR42	Internal	Strasbourg
	93	Franche-Comté	FR43	Internal	Besancon
	94	Pays de la Loire	FR51	Internal	Nantes
	95	Bretagne	FR52	Internal	Brest
	96	Poitou-Charentes	FR53	Internal	Poitiers
	97	Aquitaine	FR61	Internal	Bordeaux
	98	Midi-Pyrénées	FR62	Internal	Toulouse
	99	Limousin	FR63	Internal	Limoges
	100	Rhône-Alpes	FR71	Internal	Lyon
	101	Auvergne	FR72	Internal	Clermont-Ferrand
	102	Languedoc-Roussillon	FR81	Internal	Montpellier
	103	Provence-Alpes-Côte d`Azur	FR82	Internal	Marseille
	104	Corse	FR83	Internal	Ajaccio

Source : STREAMS, Annexe 1, pp. A1, A-5.

The STREAMS zoning system (continued)

Country	No	Zone Name	NUTS 1995 or equivalent Code	Internal External	Centroid
Ellada	105	Anatoliki Makedonia, Thraki	GR11	Internal	Kavala
	106	Kentriki Makedonia	GR12	Internal	Thessaloniki
	107	Dytiki Makedonia	GR13	Internal	Kozani
	108	Thessalia	GR14	Internal	Larissa
	109	Ipeiros	GR21	Internal	Ioannina
	110	Ionia Nisia	GR22	Internal	Kerkyra
	111	Dytiki Ellada	GR23	Internal	Patrai
	112	Sterea Ellada	GR24	Internal	Lamia
	113	Peloponnisos	GR25	Internal	Tripolis
	114	Attiki	GR3	Internal	Athinai
	115	Voreio Aigaio	GR41	Internal	Mytilini
	116	Notio Aigaio	GR42	Internal	Ermoupolis
	117	Kriti	GR43	Internal	Irakleion
Ireland	118	Dublin, Mid-East	IE11 (IE002-3)	Internal	Dublin
	119	Border, Midland-West	IE12 (IE001, IE004, IE008)	Internal	Galway
	120	Mid-West, South-East, South-West	IE13 (IE005-7)	Internal	Cork
Italia	121	Piemonte	IT11	Internal	Torino
	122	Valle d'Aosta	IT12	Internal	Aosta
	123	Liguria	IT13	Internal	Genova
	124	Lombardia	IT2	Internal	Milano
	125	Trentino-Alto Adige	IT31	Internal	Bolzano
	126	Veneto	IT32	Internal	Venezia
	127	Friuli-Venezia Giulia	IT33	Internal	Trieste
	128	Emilia-Romagna	IT4	Internal	Bologna
	129	Toscana	IT51	Internal	Firenze
	130	Umbria	IT52	Internal	Perugia
	131	Marche	IT53	Internal	Ancona
	132	Lazio	IT6	Internal	Roma
	133	Abruzzo	IT71	Internal	Pescara
	134	Molise	IT72	Internal	Campobasso
	135	Campania	IT8	Internal	Napoli
	136	Puglia	IT91	Internal	Bari
	137	Basilicata	IT92	Internal	Potenza
	138	Calabria	IT93	Internal	Reggio
	139	Sicilia	ITA	Internal	Palermo
	140	Sardegna	ITB	Internal	Cagliari
Luxembourg	141	Luxembourg	LU	Internal	Luxembourg
Nederland	142	Groningen	NL11	Internal	Groningen
	143	Friesland	NL12	Internal	Leeuwarden
	144	Drenthe	NL13	Internal	Emmen
	145	Overijssel	NL21	Internal	Enschede
	146	Gelderland	NL22	Internal	Apeldoorn
	147	Flevoland	NL23	Internal	Lelystad
	148	Utrecht	NL31	Internal	Utrecht
	149	Noord-Holland	NL32	Internal	Amsterdam
	150	Zuid-Holland	NL33	Internal	Rotterdam
	151	Zeeland	NL34	Internal	Middelburg
	152	Noord-Brabant	NL41	Internal	Eindhoven
	153	Limburg (NL)	NL42	Internal	Maastricht

Source : STREAMS, Annexe 1, pp. A1, A-5.

The STREAMS zoning system (continued)

Country	No	Zone Name	NUTS 1995 or equivalent Code	Internal External	Centroid
Portugal	154	Norte	PT11	Internal	Porto
	155	Centro (PT)	PT12	Internal	Coimbra
	156	Lisboa e Vale do Tejo	PT13	Internal	Lisboa
	157	Alentejo	PT14	Internal	Evora
	158	Algarve	PT15	Internal	Faro
Sverige	159	Stockholm	SE01	Internal	Stockholm
	160	Östra Mellansverige	SE02	Internal	Uppsala
	161	Småland med Öarna	SE03	Internal	Jönköping
	162	Sydsverige	SE04	Internal	Malmö
	163	Västsverige	SE05	Internal	Göteborg
	164	Norra Mellansverige	SE06	Internal	Gävle
	165	Mellersta Norrland	SE07	Internal	Sundsvall
	166	Övre Norrland	SE08	Internal	Umea
United Kingdom	167	Cleveland, Durham	UK11	Internal	Middlesbrough
	168	Cumbria	UK12	Internal	Carlisle
	169	Northumberland, Tyne and Wear	UK13	Internal	Newcastle upon Tyne
	170	Humberside	UK21	Internal	Kingston upon Hull
	171	North Yorkshire	UK22	Internal	Harrogate
	172	South Yorkshire	UK23	Internal	Sheffield
	173	West Yorkshire	UK24	Internal	Leeds
	174	Derbyshire, Nottinghamshire	UK31	Internal	Nottingham
	175	Leicestershire, Northamptonshire	UK32	Internal	Leicester
	176	Lincolnshire	UK33	Internal	Lincoln
	177	East Anglia	UK4	Internal	Cambridge
	178	Bedfordshire, Hertfordshire	UK51	Internal	Luton
	179	Berkshire, Buckinghamshire, Oxfordshire	UK52	Internal	Reading
	180	Surrey, East-West Sussex	UK53	Internal	Brigthon
	181	Essex	UK54	Internal	Southend-On-Sea
	182	Greater London	UK55	Internal	London
	183	Hampshire, Isle of Wight	UK56	Internal	Southampton
	184	Kent	UK57	Internal	Maidstone
	185	Avon, Gloucestershire, Wiltshire	UK61	Internal	Bristol
	186	Cornwall, Devon	UK62	Internal	Plymouth
	187	Dorset, Somerset	UK63	Internal	Bournemouth
	188	Hereford & Worcester, Warwickshire	UK71	Internal	Warwick
	189	Shropshire, Staffordshire	UK72	Internal	Newcastle-under-Lyme
	190	West Midlands (County)	UK73	Internal	Birmingham
	191	Cheshire	UK81	Internal	Warrington
	192	Greater Manchester	UK82	Internal	Manchester
	193	Lancashire	UK83	Internal	Blackpool
	194	Merseyside	UK84	Internal	Liverpool
	195	Clwyd, Dyfed, Gwynedd, Powys	UK91	Internal	Wrexham Maelor
	196	Gwent, Mid-South-West Glamorgan	UK92	Internal	Cardiff
	197	Borders, Central, Fife, Lothian, Tayside	UKA1	Internal	Edinburgh
	198	Dumfries & Galloway, Strathclyde	UKA2	Internal	Glasgow
	199	Highlands, Islands	UKA3	Internal	Inverness
	200	Grampian	UKA4	Internal	Aberdeen
	201	Northern Ireland	UKB	Internal	Belfast

Source : STREAMS, Annexe 1, pp. A1, A-5.

Table 1. The STREAMS zoning system (continued)

Country	No	Zone Name	NUTS 1995 or equivalent Code	Internal External	Centroid
Shqipëria	202	Shqipëria	AL	External	Tiranë
Bosna i Hercegovina	203	Bosna i Hercegovina	BA	External	Sarajevo
B_lgarija	204	B_lgarija	BG	External	Sofija
Belarus	205	Belarus	BY	External	Minsk
Schweiz	206	Schweiz (West)	CH1	External	Bern
	207	Schweiz (East)	CH2	External	Zürich
_esko	208	_esko	CZ	External	Praha
Eesti	209	Eesti	EE	External	Tallinn
Hrvatska	211	Hrvatska	HR	External	Zagreb
Magyarország	210	Magyarország	HU	External	Budapest
Island	212	Island	IS	External	Reykjavik
Lietuva	213	Lietuva	LT	External	Vilnius
Latvija	214	Latvija	LV	External	Riga
Moldova	215	Moldova	MD	External	Chisinau
Republica Makedonija	216	Makedonija	MK	External	Skopje
Norge	217	Norge	NO	External	Oslo
Polska	218	Polska (East)	PL1	External	Warszawa
	219	Polska (North-West)	PL2	External	Poznan
	220	Polska (South-West)	PL3	External	Wroclaw
România	221	România	RO	External	Bucuresti
Rossija	222	Rossija (Moskva)	RU1	External	Moskva
	223	St. Petersburg	RU2	External	St. Petersburg
Slovenija	224	Slovenija	SI	External	Ljubljana
Slovensko	225	Slovensko	SK	External	Bratislava
Türkiye	226	Türkiye	TR	External	Istanbul
Ukraina	227	Ukraina	UA	External	Kyiv
Jugoslavija	228	Jugoslavija	YU	External	Beograd
West Africa and the Americas	229	America	AM	External	Model node
East Africa, Asia, Australasia	230	Asia	AS	External	Model node
Egypt and the Middle East	231	Middle East	ME	External	Cairo
Morocco, Algeria, Turnisia, Libya	232	North Africa	NA	External	Alger

Note: NUTS regions ES7, FR9, PT2, PT3 which are not part of the European Continent have been excluded in the above zoning scheme.

Source : STREAMS, Annexe 1, pp. A1, A-5.